(12) UK Patent Application (19) GB (11) 2 265 805 (13) A

(43) Date of A publication 06.10.1993

(21) Application No 9304934.4

(22) Date of filing 10.03.1993

(30) Priority data
(31) 4207694 (32) 11.03.1992 (33) DE

(71) Applicant
Leybold Durferrit GmbH

(Incorporated in the Federal Republic of Germany)

Bonner Strasse 498, D-5000 Cologne 51, Federal Republic of Germany

(72) Inventors
Alok Choudhury
Matthias Blum
Norbert Ludwig
Harald Scholz
Michael Hohmann
Franz Hugo

(74) Agent and/or Address for Service
E N Lewis & Taylor
5 The Quadrant, Coventry, CV1 2EL, United Kingdom

(51) INT CL[5]
H05B 11/00 3/62 6/30 6/44 // H05B 6/24

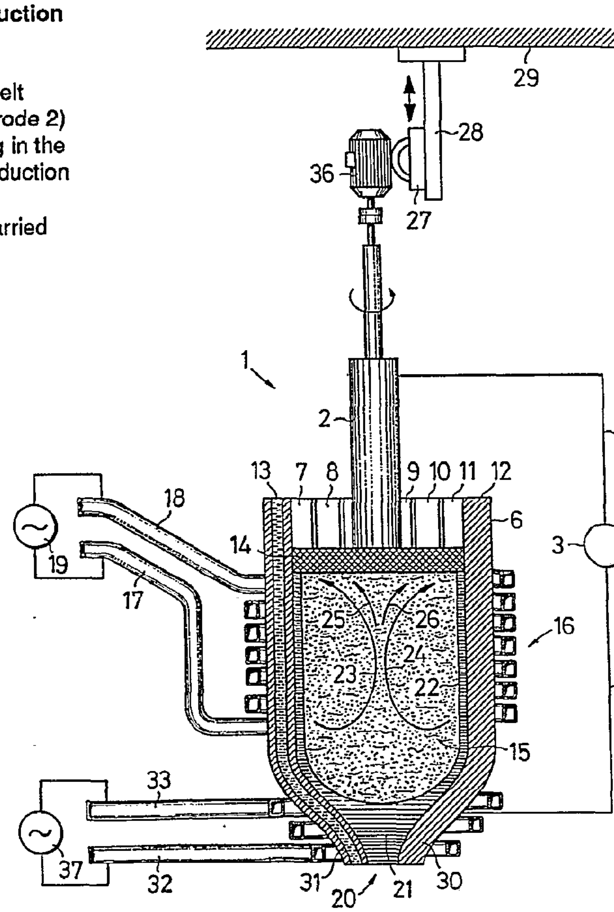
(52) UK CL (Edition L)
H5H HNX H2G2X1 H252 H3X
U1S S1612 S1974

(56) Documents cited
GB 1045604 A WO 88/00426 A1

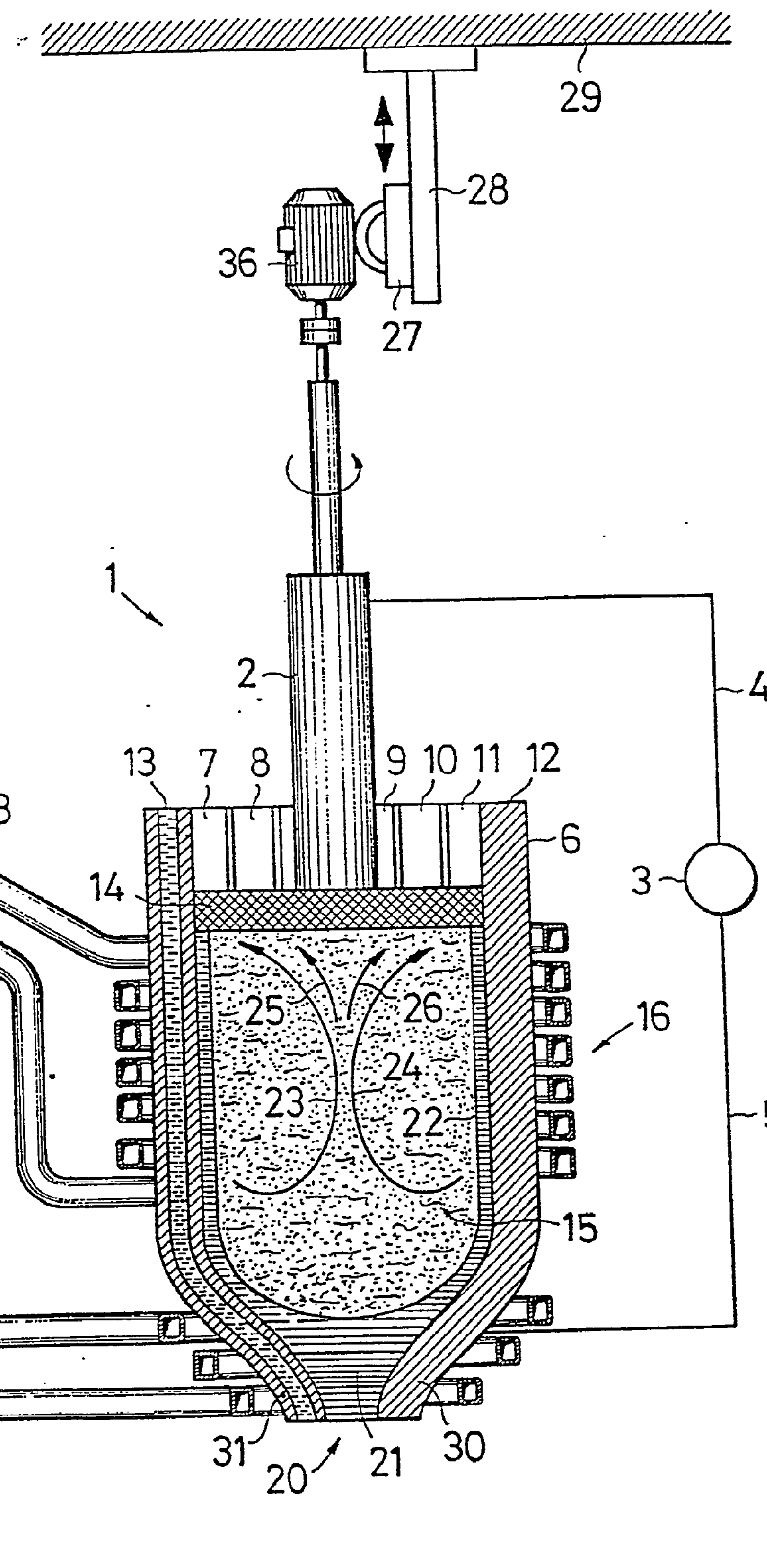
(58) Field of search
UK CL (Edition L) **H5H HNX**
INT CL[5] **F27B 14/06, F27D 11/04 11/06, H05B 11/00**

(54) **A combined electro-slag remelting/cold induction crucible system**

(57) Water cooled induction coil 16 maintains the melt created by the electro-slag remelting process (electrode 2) in a liquid form, a plug 21 of solid material remaining in the outlet of the crucible. This plug may be melted by induction coil 31 to discharge the crucible. By control of the electrode 2 a continuous melting process may be carried out. Various options of metal output are disclosed.



GB 2 265 805 A


29
28
36
27
1
2
4
13
7
8
9
10
11
12
6
18
3
14
19
17
25
26
16
24
23
22
5
15
33
37
32
31
20
21
30

ARRANGEMENT FOR THE PRODUCTION OF HIGH-PURITY METALS AND METAL ALLOYS

The invention relates to an arrangement according to the preamble of Patent Claim 1.

Highly stressed parts, for example turbine blades must be produced of a material having high purity. If in the material are enclosed foreign substances, these inclusions under high stress become starting points of hairline fractures and the like which finally lead to the destruction of the entire part.

A conventional process for producing highly pure metal or metals alloys comprises that a starting material is remelted through vacuum induction melting (VIM) into an ingot. The purity of the ingot obtained in this way, however, is still not sufficient for many cases. Moreover, it has as a rule an inhomogeneous structure which inter alia can be traced back to the fact that the solidification of the metal in a form which determines the outer contours of the ingot takes place from the outside toward the inside. In order to achieve a still higher degree of purity, the ingot is subjected to a vacuum arc remelting (VAR) process. The ingot has herein the form of a cylindrical electrode connected to one pole of an electrical voltage source while the container into which falls the material dropping from the electrode is connected to the other pole of this voltage source. In that case between the electrode and the ingot to be produced in the chill mould an arc is formed which leads to the melting off of the one end of the ingot electrode.

In another known process, the electro-slag remelting (=ESR cf.DE-Z:Korousic,B.et al.:ESR Technology of High Purity Copper Alloys, Metall,February 1987,pages 153 to 155) process, no open arc is formed between an electrode and melt material in a chill mould even though an electrical voltage in similar form is applied as in the VAR process (German allowed patent application No. 2349721). Hereby through the current flow via an electrode immersed in the slag, the slag is heated by resistance heating whereby the electrode material melts off. The melted-off material penetrates the slag. Between the melt

material and the slag surface therein metallurgical reactions take place so that below the slag a melt material of high purity is disposed. An advantage of the ESR process comprises that it can be carried out at normal atmospheric pressure.

The work pieces themselves, for example turbine parts, can be produced from the purified material by forging. But it is also possible to atomize the purified and liquified material to form powder, place it into a mould vessel, and densify it subsequently through mechanical pressure.

In the VAR process as well as in the ESR process the heat energy required for melting is introduced through the current flow across a resistor.

In so-called inductive heating the melting energy, in contrast, is introduced into the melt material through eddy currents which, in turn, are generated by a magnetic ac field in a coil. Herein this coil is disposed about a crucible in which is disposed the melt material (German Patent No. 3026722).

In order for the magnetic fields to be able to permeate the melt material, the crucible must completely or at least partially be permeable to these fields. If the crucible comprises ceramics, the fields permeate into the melt material without problems. In the case of ceramic crucibles in which metal is being melted, the problem exists that while they have a high melting temperature and allow magnetic ac fields to penetrate, they react in some cases with the melt or parts of the brittle crucible ceramic become detached and are brought into the melt as inclusions.

Metal crucibles, in contrast, have a high degree of toughness and do not directly react with the melt. Their disadvantage lies in the fact, that eddy currents develop in them and the magnetic ac fields are prevented from permeating into the melt material. They have, in addition, a relatively low melting temperature.

It is already known to use metal crucibles in spite of the stated negative properties for inductive melting of metals and metal alloys (DEP 518 499, EP 0 276 544, DE-A-39 40 029, EP-A-0 480 845). Herein, on the one hand, the crucible wall is divided into several segments in order to decrease the formation of shielding eddy currents and to permit in this way an inductive heating of the melt material, and, on the other hand, the crucible segments are for example cooled by water so that they are not melted by a potentially higher

temperature of the melt material. By implementing the crucible segments in a special way the introduction of energy into the melt material can be optimized. It is moreover for example possible through the radiation pressure of the fields emanating from the coil to keep the melt from the inner wall of the crucible. In the cooled induction crucible a melt is generated which subsequently is removed from the crucible by tilting it. It is however also known to provide at the bottom of such a crucible an opening and to atomize the melt stream flowing out of it so that a metal powder or metal oxide power is formed (DE-A-40 11 392). For shaping the pouring stream therein a conical or rotationally hyberbolic funnel is provided comprising metallic fluid-cooled segments and surrounded by an induction coil. Through the shape of the funnel, through the selection of the ac current frequency with which the induction coil is operated, and through the selection of the current distribution of the induction coil the pouring stream can be shaped and spread.

The invention is based on the task of generating a pouring stream comprising a material which compared to the materials produced with the stated processes has an increased purity.

This task is solved according to the features of Patent Claim 1.

The advantages achieved with the invention comprise the purification of the ESR electrode material by means of slag reactions, the purification of the liquified melt material through superheating in the induction oven as well as potentially in the concentration of the impurities in the cap on the cold crucible surface. Furthermore, through the linkage of two technologies in one installation and in one melting process compared to separate installations, considerable energy savings, shortening of the duration of the process and, potentially, a higher purity can be achieved. These advantages are additionally supplemented by a large spectrum in the end products. The process, moreover, can be carried out under nearly any given type of atmosphere, for example <u>in vacuo</u>, in air, in inert gas and under excess pressure. In the combination installation is preferably integrated an outlet which permits the realization of the process conditions which are the most favorable for the particular end product.

Added to this is the fact that the arrangement according to the invention can be operated <u>in vacuo</u> as well as also in air or in an inert gas

chamber or under excess pressure.

An embodiment example of the invention is depicted in the drawing and will be described in greater detail in the following.

In the Figure is depicted an arrangement 1 in which elements of the electro-slag remelting process are linked with elements of the induction crucible technology. The melting of an electrode 2 therein takes place by means of an electrical energy source 3 whose first terminal 4 is connected with the electrode 2 while its second terminal 5 is connected to a crucible 6. A starter plate, not shown in the Figure, can also be provided. The energy source 3 can moreover be a dc or ac current source. This crucible 6 is a slotted crucible comprising several vertically disposed fins of which only some fins 7 to 13 are visible in the Figure. The end of electrode 2 is immersed in a liquid slag layer 14 and is there melted off due to the high heat development in the slag layer 14. The melted and purified melt material 15 collects underneath the slag layer 14. Up to this point it is the conventional electro-slag remelting process. In this known process underneath the slag layer 14 down to a particular depth a sump develops comprising liquified electrode material 15 . Underneath this sump the material is again solidified. The slowness of the ESR process in general does not permit keeping liquid the entire contents of the crucible 6 underneath the slag layer 4 and possibly to pour it off through an opening in the crucible 6 and to atomize it. A continuous progression of the melting process is achieved according to the invention thereby that the crucible 6 is a cold induction crucible. This crucible has around its circumference a water-cooled induction coil 16 which is connected via two terminals 17, 18 to an ac current source 19. With the aid of this induction coil the melt material 15 can be kept in the liquid state. At the lower end of the crucible 6 is disposed an opening 20 which during the normal melting operation is closed by a stopper 21 comprising the same material as the electrode 2. This stopper 21 is formed due to the cooling through the wall of the crucible 6 or is set in place beforehand. If the melting energy coupled in via the coil 16 is not sufficient, the solidified stopper continues in a solidified layer 22 in the upward direction. The remaining melt 15 is kept in the liquid state through the induction of coil 16 and caused to form currents. These currents are illustrated by curved arrows 23

to 26 wherein the arrows indicate only symbolically the very complicated current motions and do not make any reference to the actual currents. In any case, however, the slag currents bring about that inclusions and impurities still present in the slag arrive at the outside, are picked up by the slag layer and can in this way be removed from the melt. Hereby the remelted material is once again purified.

The electrode 2 can be rotated with the aid of a motor 36. It is also possible to lower or raise vertically the electrode 2 by means of a lifting mechanism 27 movable on a vertical rail 28 and fastened on an arrangement 29.

If the melt 15 is sufficiently purified, it can be removed from the crucible 6 for further processing. For this purpose a further induction coil 31 is provided at the lower end 30 of the crucible 6 which is fed from an ac current source 37. If through this coil 31 a current flows, the induction heat energy is concentrated on the stopper 21 and melts it. After this stopper has been melted, the liquid material 15 can stream from the crucible 6 through the opening 20 downwardly and can be processed further to form metal and alloy powder. It is also possible to produce semifinished products via continuous casting or bottom retraction. This process can also be carried out continuously by means of melting off the electrode and pouring off the material.

This further processing is known per se (cf. for example USP 4 762 553, USP 4 869 469) and for that reason does not need to be described further. It is understood that the known cold-finger technology can be used for pouring off the stream or that an ingot retractor device is used. The ac current of source 3, which is used for the ESR process proper, can have variable frequencies. Instead of one electrode 2, two or more electrodes can also be melted simultaneously. In the case of three electrodes the current source 3 can be a three-phase current source.

For heating the melt 15 two separate ac current sources 19, 37 are depicted in the Figure. Instead of two ac current sources, it is however also sufficient to have one if it can be switched to one or the other winding.

The invention can also advantageously be combined with the cold-finger technology for pouring off streams (A. Gubchenko, Y. Norikov, A. Choudhury, F. Hugo: Vacuum Induction and Induction Plasma Furnaces with Cold Crucible,

Paper presented at the Vacuum Metallurgy Conference, 1991, Pittsburgh/USA) or with an ingot retractor device (A. Choudhury: Vacuum Metallurgy, ASM International, 1990, pp. 136, 137).

A pouring stream coming from the crucible 6 can be transferred into a chill mould where it solidifies to form an ingot. It is also possible to use a pouring stream from the crucible 6 for filling lost-wax moulds. The pouring stream can moreover be atomized by means of inert gas so that fine metal powder is produced. Furthermore, from the tapered region of the crucible 6 a continuous rope can be drawn whose diameter is variable. The induction coil 16 can be divided into two or more parts which are connected to the same or to different voltages.

Patent Claims

1. Arrangement for the production of high-purity metals and metal alloys with a cooled crucible comprising one or several metallic segments, which is surrounded by an induction coil, **characterized in that** in the crucible (6) a liquid slag layer (14) is provided in which is immersed at least one electrode (2) comprising a metal or a metal alloy, and that this electrode (2) is connected to a voltage source (3).

2. Arrangement as stated in Claim 1, **characterized in** that a metal plate is provided as an opposing electrode.

3. Arrangement as stated in Claim 1, **characterized in** that into the slag layer (14) are immersed two or more electrodes comprising a metal or a metal alloy, and that these electrodes are connected to a voltage source (3) wherein one or several electrodes serve as opposing electrodes.

4. Arrangement as stated in Claim 1, **characterized in** that the crucible (6) has in its bottom an opening (20).

5. Arrangement as stated in Claim 1, **characterized in** that the crucible (6) tapers in the direction toward its bottom and the tapered region of the crucible is surrounded by an induction coil (31) which is connected to an ac voltage source (37).

6. Arrangement as stated in Claim 1, **characterized in** that the electrode (2) is rotatable about its longitudinal axis by means of a drive (36).

7. Arrangement as stated in Claim 1, **characterized in** that the electrode (2) can be lowered by means of a drive (27).

8. Arrangement as stated in Claim 4, **characterized in** that the opening (20) is closed by a stopper (21) comprising the same material as the electrode (2).

9. Arrangement as stated in Claim 5 and Claim 8, characterized in that the inductive heating power of the induction coil (31) is so high that the stopper (21) can be melted.

10. Arrangement as stated in Claim 1, characterized in that instead of a crucible bottom an ingot retractor device is disposed.

11. Arrangement as stated in Claim 1, characterized in that a pouring stream is transferred from the crucible (6) into a chill mould where it solidifies to form an ingot.

12. Arrangement as stated in Claim 1, characterized in that a pouring stream from the crucible (6) is used for filling lost-wax moulds.

13. Arrangement as stated in Claim 1, characterized in that powder is formed through a pouring stream from the crucible (6) by means of inert gas atomization.

14. Arrangement as stated in Claim 5, characterized in that from the tapered region of the crucible (6) a continuous rope is drawn wherein the rope diameter is variable.

15. Arrangement as stated in Claim 1, characterized in that the process is carried out _in vacuo_, air, excess pressure or inert gas.

16. Arrangement as stated in Claim 1, characterized in that the induction coil (16) is segmented.

17. Arrangement for the production of high purity metals and metal alloys substantially as hereinbefore described with reference to and as illustrated in the accompanying drawing.

18. A method for the production of high purity metals and metal alloys substantially as hereinbefore described with reference to and as illustrated in the accompanying drawing.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

GB 9304934.4

Relevant Technical fields			Search Examiner
(i) UK Cl (Edition	L)	H5H (HNX)	J COCKITT
(ii) Int Cl (Edition	5)	H05B 11/00; F27B 14/06; F27D 11/04, 11/06	

Databases (see over)	Date of Search
(i) UK Patent Office	29 JUNE 1993
(ii)	

Documents considered relevant following a search in respect of claims 1-18

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 1045604 A (SOCIETE) - see whole document	1 at least
A	WO 88/00426 A1	

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).

Published 1993 at The Patent Office, Concept House, Cardiff Road, Newport, Gwent NP9 1RH. Further copies may be obtained from Sales Branch, Unit 6, Nine Mile Point, Cwmfelinfach, Cross Keys, Newport, NP1 7HZ. Printed by Multiplex techniques ltd, St Mary Cray, Kent.